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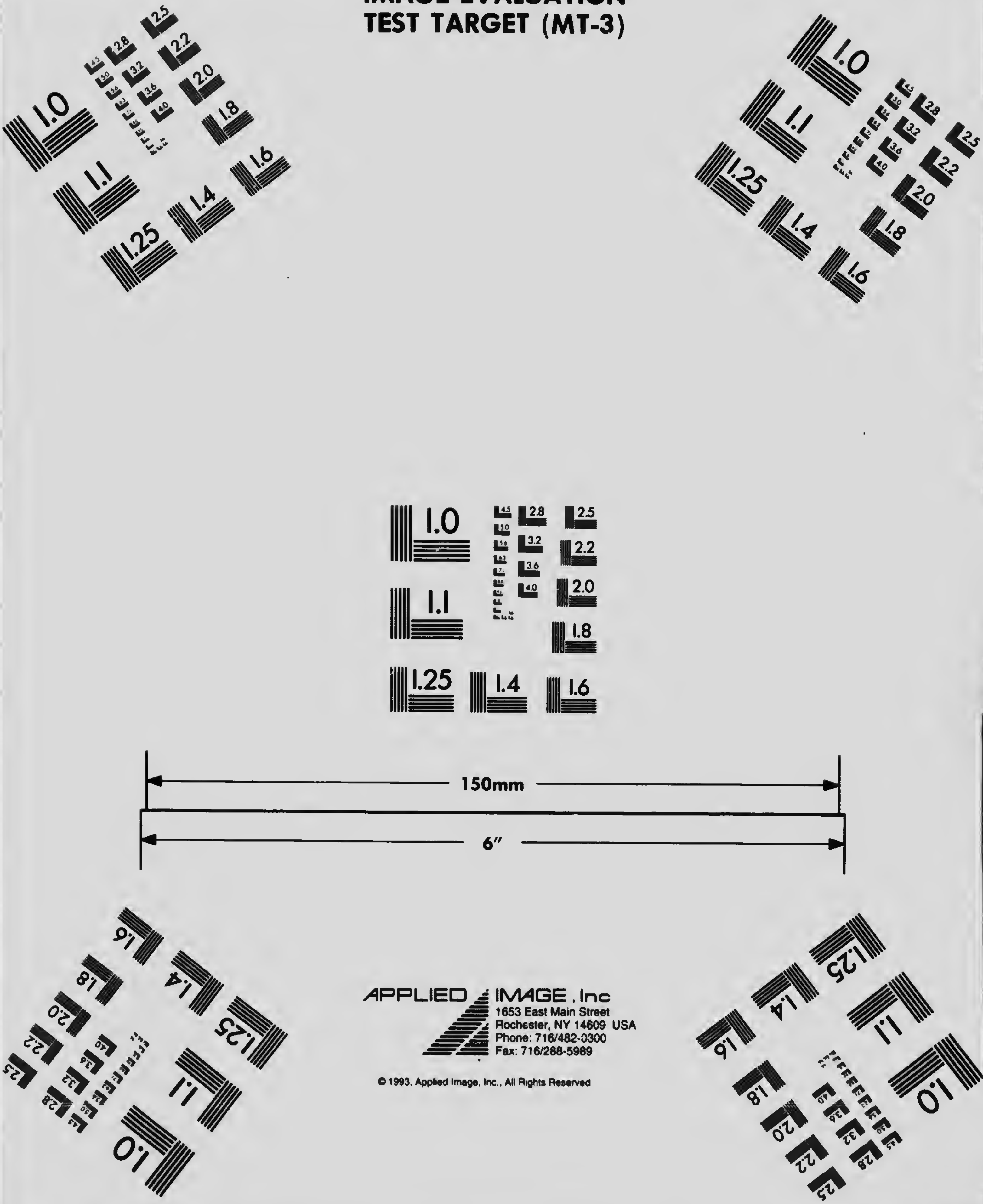

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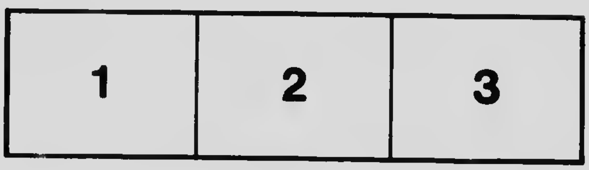
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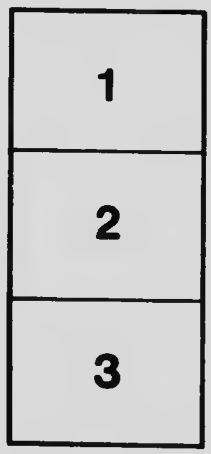
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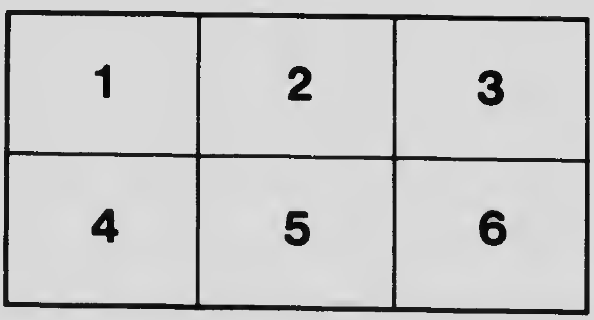
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AN ECOLOGICAL STUDY OF THE MAYFLY *CHIROTENETES*

BY

WILBERT AMIE CLEMENS, M.A.

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AN ECOLOGICAL STUDY OF THE MAY-FLY *CHIROTENETES*

Introduction

Notwithstanding the numerous investigations which have been made upon the life phases of various *Ephemeridae*, our knowledge concerning the physical factors and their co-operation in relation to individual species is singularly small. It was for this reason that the writer, on the suggestion of Professor James G. Needham, undertook and carried out during the years 1913-1915 the detailed study of a single species in a very restricted area, the results of which are described below. The species chosen for study was *Chirotenetes albomanicatus* Needham, the nymph of which is common in and characteristic of the riffles and rapids of the streams of the Cayuga basin. The various stages of the insect are described by Needham ('05). The description is illustrated by two plates and is accompanied by some data on the habits of the nymph and subimago and the food of the nymph. Morgan ('11) gives some brief observations made on this species in Fall Creek, and again ('13) gives further biological data with illustrations of gills and egg.

The writer is greatly indebted to Professor Needham for invaluable advice and for many helpful suggestions freely given during the course of the investigation.

The Nymph

General Habitat.—The nymph of *Chirotenetes albomanicatus* inhabits all the larger streams in the vicinity of Ithaca, New York, but this study has been mainly confined to one stream, Cascadilla Creek. (Contour map, Fig. 1.) It was chosen chiefly because its smaller size made it much more accessible for observation and experimental work. The creek has an approximate length of eight miles. It arises in an upland alder swamp and flows in a westerly direction, emptying into Cayuga Lake Inlet. The stream may be divided into three regions: (1) an upland portion approximately six miles in length where the stream occupies a preglacial drift-filled valley; (2) a gorge portion one mile in length where the stream flows through a gorge which has been cut back in the Devonian shale from the edge of Cayuga valley; (3) a flats portion one mile in length where the stream flows through the sediment deposited at the head of Cayuga Lake by the tributary streams. At its source the stream winds among the alders, flowing over a bed of dark brown vegetable débris, and then, emerging into meadow land, it takes a winding course in the open, its banks bordered with shrubs and scattered trees. The average width is 18 feet. The descent averages 36 feet per mile, producing a moderate current over a bed of gravel and stones, with accumulations of stones and rubble* forming numerous riffles and rapids. Tributaries arising from springs in the surrounding hills increase the volume of the water. The nymphs of *Chirotenetes* occur very abundantly in the riffles and rapids of this upland portion. The creek has a much swifter current in the gorge, spreading out in broad sheets over the smooth rock bottom and tumbling over ledges. *Chirotenetes* nymphs are found under stones and rubble and occasionally on the rock bottom. After descending into Cayuga valley the stream takes a straight north-westerly course, passing over a bed formed of materials brought down from the heights. These materials form an intergrading series. The larger stones and pieces of rock occur at the base of the hill, and then follow in succession smaller stones and rubble, gravel, sand, silt. For the last 250 yards of its course the stream broadens out and becomes deep and sluggish because of the backing up of the water from the lake. The nymphs of *Chirotenetes* are abundant at the base of the hill but gradually decrease in

*The term rubble is used to designate the flat fragments of shale and limestone as distinguished from the stones with rounded edges tending toward a spherical form.

Fig. 1.—Contour map from topographic sheets of the United States Geological Survey.

CHEMICAL ANALYSIS OF THE WATER OF CASCADILLA CREEK

All results in parts per million

Date	Temp.	Oxygen	Free CO_2	Normal Car-bonates	Biscar-bonates	Free NH_3	Alb. NH_3	Oxygen Con-sumed	Nit-rites	Nit-rates	Chlo-rine	Alka-linity	Phos-phates	Sul-phates	Iron
1914															
Dec. 1	10°	9.4	3.0	0					.001			108			
" 8	3°	12.1	2.0	0		.01	.08		.006		2.8	119			
" 15	3°	12.1	1.5	0						.3		120			
" 22	3°	12.2	2.0	0	53.4										
1915															
Jan. 12	3°	12.5	.0	0	29.9	.07	.021	4.05	.001		3.0	64			
" 19	0°	12.4	2.0	0	15.2			6.6		.5	2.5	33			
Feb. 16			3.0	0	16.6			1.0				36			
" 23	1.7°	11.6	2.5	0	22.5	.035	.125	3.95				46			
Mar. 5	0°	13.0	2.0	0	17.6										
" 19	0°	13.6	2.5	0	37.7	.01	.047	1.1		.5	2.5	75			
Apr. 13	5°	12.8	2.0	0	21.0	.011	.142	1.45	.001	.1	3.5	60			
" 20	4°	12.7										80	trace	31.8	
May 12	14°	9.7	1.0	0	40.6	.037	.118	1.9	.001	trace	2.5	71			
" 18	8°	11.2	.7	0	38.7							96		34.8	
June 17	22	8.0	1.5	0	52.9	.058	.101	4.25		.025	2.0	116	trace	33.3	.42
July 14	20.5°	8.7	.0	7.8	32.3			2.8			1.5	74			
" 15	20.5°	8.7	.0	9.8	31.8										
" 21	17°	9.8	.0	9.8	44.6							120			
" 30	23.2°	10.0	.0	13.7	48.5						3.0				
Aug. 10	19°	8.8	.0	15.6	38.7	.04	.04	3.8		.1	2.0	103			

numbers toward the mouth, disappearing when the slack water is reached.

Chemical Analyses of the Water.—In order to obtain definite knowledge concerning the medium in which the nymphs live, chemical analyses were made at various times from December 1, 1914, to August 10, 1915. The results are given in tabular form. Comparison with analyses of the water of the neighbouring Fall Creek shows a very close correspondence. The amount of pollution is not excessive as indicated by the nitrogen determinations as free and albuminoid ammonia, nitrites, nitrates, oxygen consumed, chlorine and alkalinity. The oxygen content is high throughout the year,

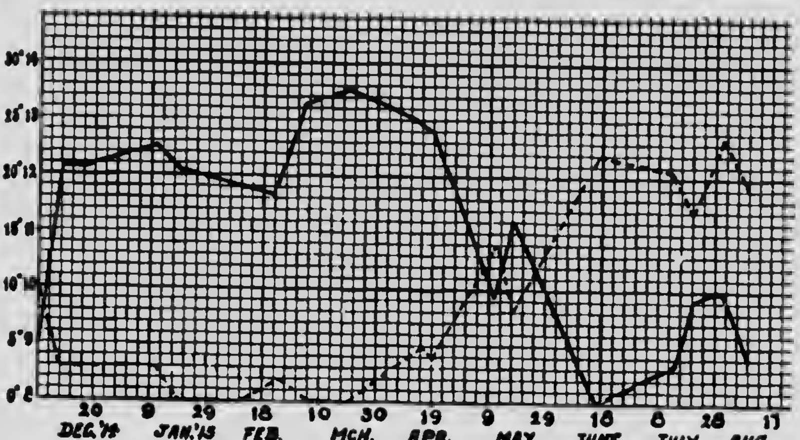


Fig. 2.—Relation of the oxygen content to temperatures of Cascadilia Creek.
——— = oxygen in parts per million at 760 mm. pressure.
- - - - - - = temperature.

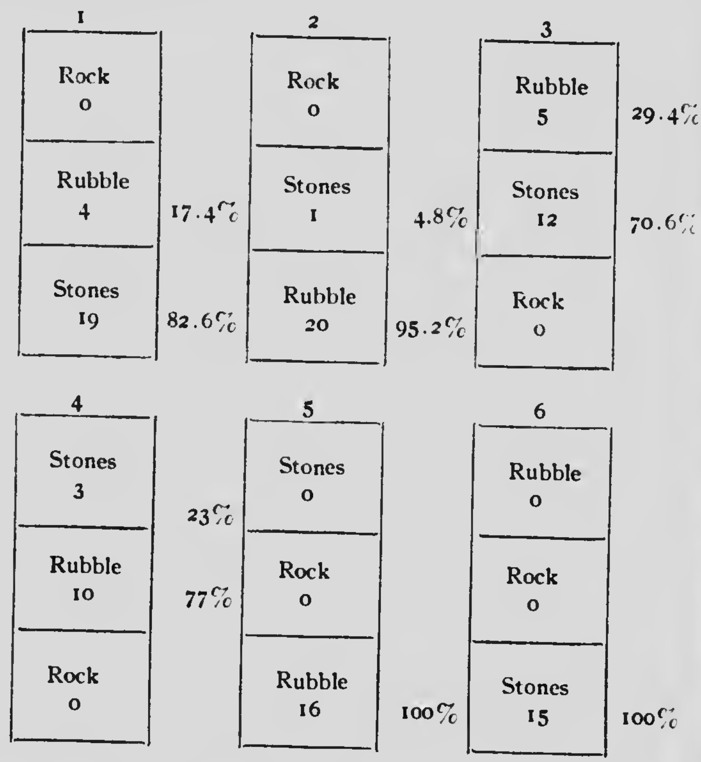
doubtless as a result of the turbulent nature of the creek. Figure 5 shows the amounts of oxygen present reduced to 760 mm. pressure as compared with the amounts of saturation at the same temperatures and pressures. The carbon dioxide content is low, probably for the same reason that the oxygen content is high.

Temperatures.—Records of the temperatures of the water in Cascadilla Creek were taken almost daily for over a year for the purpose of obtaining information regarding the fluctuation in temperature from day to day, the maximum summer temperature, the length of the zero period, and the relation between the temperature and the oxygen content in a swiftly flowing stream. The records show that the water temperature fluctuates with the air temperature but never reaches the extremes of the latter. The highest temperature recorded during this period was 28° C. on June 25, 1914. The maximum air temperature on this day, as recorded by the Weather Bureau branch of the United States Department of Agriculture at Ithaca, New York, was 29.9° C. and the day before 32.2° C. The temperature remained at 0° C. from November 8, 1914, to March 28, 1915, except for a rise to 3° C. during four days in February, 1915. The relation of the oxygen content during the year to the temperature of the water is shown in Fig. 2.

Relation to Materials Forming the Creek Bed.—Field observations show that the nymphs of *Chirotenetes* occur in greatest numbers in those parts of the stream where there are deposits of rubble and stones in moderate to swift current. They occur most abundantly in the upland portion of the creek and so numerous at times are they in places that as many as sixteen nymphs of various sizes have been found beneath a stone of 3 x 4 inches, which would mean a nymph to each three-quarters of a square inch. Forty nymphs have been found beneath a piece of rock about one foot square. Frequently a flat shelving piece of rock may be lifted slightly and the nymphs observed clinging to the under surface in company with other may-fly nymphs such as *Epeorus*, *Heptagenia*, *Ecdyurus* and *Baetis*, stonefly nymphs, caddis worms and the water-penny. Needham ('05) reports some observations which he made in Fall Creek gorge. "I have observed the nymph, especially in those places where the creek bed is flat shelving rock over which the water streams in a thin sheet. In such places the flat, rocky floor of the stream is covered with a thin filmy growth of algae, with abundant nets of the caddis seine-maker, *Hydropsyche;* and the broken edges of the floor ledges are fringed with black masses of blackfly larvae, *Simulium*. *Simulium* and *Hydro-*

psyche are fixed in their places, but *Chirotenetes* wanders about freely over the ledges, clinging securely even in the swiftest water, keeping of necessity head up stream, moving by short quick dashes effected by sharp strokes of its powerful tail fin and gill covers, moved synchronously. It is found in the stiller pools at the sides of the current, in which dwell other may-flies of the genera *Caenis* and *Baetis*; and also among the rocks in the current under which cling other nymphs of *Heptagenia*, *Blasturus* and *Choroterpes*."

Field observations appeared to indicate that the lower sides of stones and rubble contribute the preferred habitat of *Chirotenetes*. In order to test the matter, however, certain experiments were devised. These were based on the assumption that the nymphs would not remain in a situation which did not suit them if a more suitable situation were available. A wooden trough three feet long, one foot wide and ten inches deep was constructed and provided with wire netting at both ends, so as to allow water to flow through freely but preventing anything in the trough from escaping. In the upper end of the trough was put a flat stone a foot square. The small crevices between the stone and the sides of the trough were filled in with fine gravel. Behind the stone for the remaining length of the trough course gravel was placed for a depth just equal to the thickness of the stone. In the middle of the trough there was placed a pile of rubble each piece about 3½ inches square. At the lower end was put a pile of small stones, each stone about 1½ inches in diameter. Just enough space was left between these groups of materials to allow a wire screen to be pushed down between them. The trough was then placed in the stream and arranged so that there was a current through the trough of 1 to 2 $^{3}/_{10}$ feet per second according to the depth of the water. Then twenty-four almost mature *Chirotenetes* nymphs were put in the trough at the lower end. At the end of twenty-four hours the screens were carefully put in position between the groups of materials, the trough taken from the stream, the materials carefully removed and the nymphs in each section counted. Nineteen were found among the small stones, four in the rubble, and none on the rock. A series of such experiments was tried; the arrangement and results of a typical set are given as follows:



In all cases the nymphs were put into the trough at the lower end. In conducting the fifth test a blocking of the screen at the lower end of the trough one day caused an almost complete cessation of current, and when the trough was examined it was found that all the nymphs except one had migrated to the upper end, close to the screen where there was a slight movement of water. This appeared to indicate that current was a more important factor than material in the selection of a habitat. The results of these experiments indicate that the nymphs have a decided aversion to open rock and a slight preference for rubble as against small stones.

Relation to Light.—It was thought that light might be an important factor in the choice of habitat. Wodsedalek ('11) has shown by experiments that the nymphs of *Heptagenia interpunctata* Say are to a strong degree negatively phototactic. An experiment was devised to determine the reactions of *Chirotenetes* nymphs to light. A trough 51×4×3⅛ inches, with wire screens at the ends, was divided into three equal compartments by means of cross pieces reaching from the upper edge to within an inch of the bottom. A similar cross piece was put at the lower end against the screen. At the upper end was a small intake area where the water entered before flowing into the three remaining compartments. The trough was then put out in the stream under a small ledge where a current of water could easily be sent through the trough and where conditions of light were normal. The amount of water was then regulated so that the surface just reached the lower edges of the partitions. The bottom of the trough was rough, offering a foothold for the nymphs. Thirteen *Chirotenetes* nymphs were put in the lower compartment over which a close-fitting cover was immediately placed. At the end of two and one-half hours not a single nymph had left the compartment. Then the cover was taken off and placed over the upper compartment. Immediately the nymphs began to migrate up the trough. In four minutes all but four had disappeared into the upper compartment and seven minutes later the remaining four had disappeared also. Not one ventured beyond into the small open intake area. After waiting ten minutes the cover was removed and all the nymphs were driven back into the lower compartment again and the cover replaced. At the end of ten minutes all the nymphs were still in this part. Then the cover was removed and quickly placed over the middle compartment. At once the nymphs began to migrate and in two minutes all

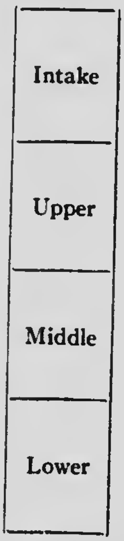


Fig. 3. Diagram of trough used in experiments to determine relation of nymphs to light factor.

except one had disappeared into the darkened chamber, the last one following in forty-five seconds. The trough was left in this condition for seventeen hours and at the end of this time every nymph except one still remained in the middle darkened compartment. When the cover was removed the nymphs scattered. The cover was placed over the lower compartment again and when the trough was examined six and a half hours later all the nymphs were down in the covered area. These experiments were repeated many times. The nymphs thus show very strong negatively phototactic tendencies.

The trough used in the experiment for habitat preference was then used to determine whether or not the nymphs would remain on the bottom of the trough if the empty area were darkened, in preference to moving where the stones and rubble were. Since the nymphs appeared to show no very decided preference as between stones and pieces of rock, the trough was divided into two areas only, one with stones and pieces of rock, the other without any materials, leaving the rough bottom of the trough as a surface to which the nymphs might cling. The empty portion of the trough was closely covered and the trough put out in the current, with the stones and rubble up stream. Eighteen *Chirotenetes* nymphs were put into the lower darkened compartment. When the trough was examined twenty-four hours later, all the nymphs were found in the upper area. The trough was then reversed and the nymphs put in at the lower end among the stones and rubble. Twenty-four hours later all the nymphs were still in this area.

Judging from the results of these experiments and field observations it appears that current is the more important factor in determining the habitat of the nymph with light and materials as secondary but closely linked factors.

Relation to Current.—Since the nymphs of *Chirotenetes* are current dwellers it appeared to be desirable to obtain more accurate data in regard to the velocity of the water in which the nymphs live. For use in a stream such as Cascadilla Creek where the water is turbulent, swift, and comparatively shallow, it was necessary to have some instrument for current measurement which could be used in narrow places and give measurements at slight differences in vertical and horizontal ranges. Upon consultation with Professor E. W. Schoder of the Department of Hydraulics, Cornell University, a Pitot tube was suggested and an apparatus as shown in Figure 4 was constructed. This consists of two copper tubes 24 inches long and 3/16 inch in diameter, fastened together and having the lower ends bent at right angles so that the openings extend in opposite directions. The copper tubes are connected by means of rubber tubing sixty inches in length and a quarter inch in diameter to two glass tubes each twenty-four inches in length and 15/16 inch in diameter. The glass tubes are connected at the top and may be opened to the air by means of a stopcock. The glass tubes are attached to a board and between them is placed a scale. This instrument was rated in the canal of the Hydraulic Laboratory of Cornell University.

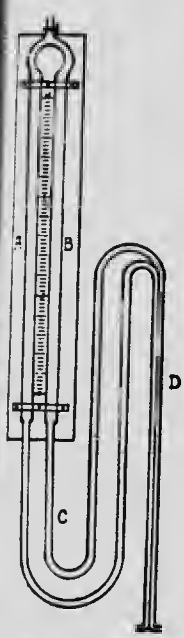
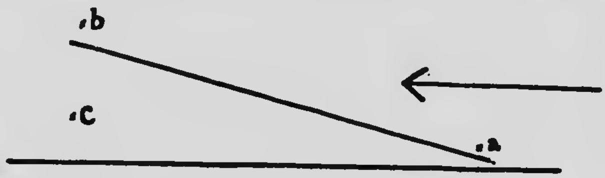


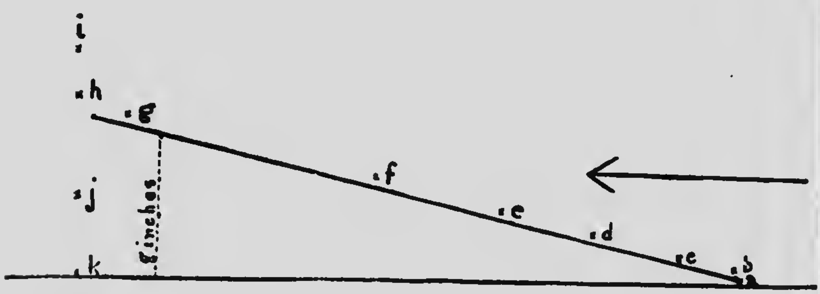
Fig. 4.—Diagram of Pitot-tube. A and B= glass tubes of gage with scale between them. C=rubber tubing. D =copper tubes.

With the Pitot tube a large number of measurements were made in Cascadilla Creek. The first measurement taken was in the middle of a small stream twenty-two inches wide and five inches deep flowing in a channel in the rock in the gorge. It was found that near the surface there was a velocity of 1.7 feet per second, while on the bottom the velocity was 1.0 foot per second. A stone with dimensions of about 12×10×2½ inches was placed in the middle of the channel. Midway between the surface of the stone and the surface of the water the velocity was 1.9 feet per second. On the surface of the stone the velocity was 1.5 feet per second; three-quarters of an inch behind the stone and one inch above the bottom there was no perceptible current; on the stream bottom behind the stone there was a slight current of not over 0.5 foot per second. A measurement in swifter water showed a velocity near the surface of 4.3 feet per second while on the bottom only 2.1 feet per second. Many measurements were taken round stones in the creek, particularly round shelving stones, and a few results are here given.



At	a	velocity	1.6	to	2.1	feet	per	second.
"	b	"	2.0	"	2.6	"	"	"
"	c	"	very low and indications of slight eddy.					

At	a	velocity	2.9	feet	per	second.
"	b	"	2.6	"	"	"
"	c	"	3.6	"	"	"
"	d	"	.0	"	"	"

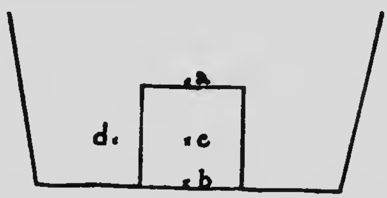


Size of stone = 12 × 22 inches.

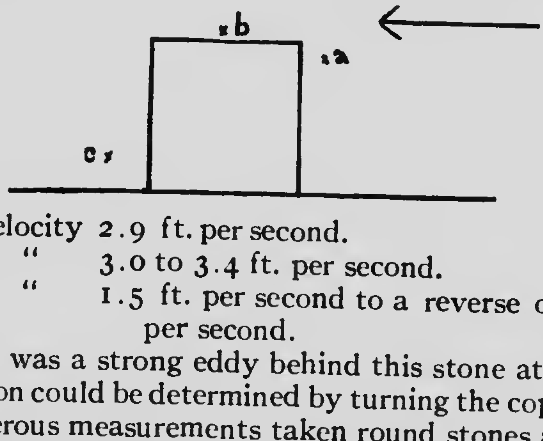
At	a	velocity	1.0	to	1.5	foot	per	second.
"	b	"	3.0	"	3.5	"	"	"
"	c	"	2.0			"	"	"
"	d	"	2.1			"	"	"
"	e	"	2.3			"	"	"

At **f** velocity 2.8 foot per second.
" **g** " 2.9 " " "
" **h** " 3.7 " " "
" **i** " 4.6 " " "
" **j** " 1.0 " " "
" **k** " too small to be measured with the Pitot tube.

In a channel 7½ inches deep and three feet wide, the bottom velocity was 1.5 feet per second; close to the surface the velocity was 2.5 feet per second. A stone almost cubical in form was put in this channel.



At **a** on top of stone velocity 2.9 ft. per second.
" **b** behind stone on bottom velocity 0.5 ft. per second.
" **c** behind stone 2½ inches above bottom velocity .0 ft. per second.
" **d** at side of stone velocity 2.8 to 3.1 ft. per second.



At **a** velocity 2.9 ft. per second.
" **b** " 3.0 to 3.4 ft. per second.
" **c** " 1.5 ft. per second to a reverse of 2.0 feet per second.

There was a strong eddy behind this stone at times and the direction could be determined by turning the copper tubes.

Numerous measurements taken round stones and rubble in the rapids and riffles of the stream have shown that nearly all are so placed that a current of greater or less velocity flows beneath them. It is in this diminished current underneath the stones and rubble that the nymphs of *Chirotenetes* live. Many of the large shelving pieces of rock have a current underneath at one point and no current at another point. The distribution of seine-making caddis worms underneath a stone gives a very good indication as to the presence or absence of a current.

Measurements were taken on July 1, 1915, over the smooth flat rock in the gorge where the water spreads out in a broad sheet and where blackfly larvae and seine-making caddis worms were very abundant. Two such measurements are typical.

Water Three Inches Deep

Close to surface – –	5.1 foot per second.
Bottom – – – –	3.7 " " "

Water Four Inches Deep

Close to surface – –	3.4 foot per second.
Midway to bottom – –	3.0 " " "
Bottom – – – –	2.0 " " "

At various times of high water in the creek measurements of the vertical distributions of velocities were taken. The results of three measurements are as follows:

Inches below surface	Velocity ft. per sec.		Velocity ft. per sec.		Velocity ft. per sec.	
2	4.5		4.5		3.9	
3	4.2		4.4		3.7	
4	4.0		4.3		3.6	
5	3.8		4.1		3.3	
6	3.7		3.8		3.0	
7			3.3		2.9	
8	3.7		3.1		2.8	
9			3.0			
10	3.4		2.9		2.7	
11						
12	3.2		2.7		2.6	
13						
14	3.0		2.4		2.5	
15	2.9				2.2	
16	2.2		2.2		1.7	Bottom
17	1.7	Bottom	1.7	Bottom		

On July 13, 1915, the smooth rock of the floor of the stream in the gorge was covered with a thin film of diatomaceous ooze, of *Navicula* and *Synedra* chiefly, just enough to make the rocks very slippery under foot. The water over the rock had a depth of one to two inches. The Pitot tube was placed on the bottom in the centre of an area of diatomaceous ooze. The velocity was 2.0 feet per second. The ooze was then cleaned off the rock over a large area and the tube placed in exactly the same position as for the first measurement and a velocity of 2.3 feet per second was obtained. There was thus a decrease in velocity of 13 per cent. due to the ooze. Numerous other measurements showed an equal or slightly smaller decrease. On rocks with a fine coating of algal growth and silt, measurements showed losses of as much as thirty per cent.

Experiments were then conducted to determine in how swift a current the nymph of *Chirotenetes* could maintain itself. A wooden trough fifty-one inches long, four inches wide, and three and one-eighth inches deep was placed at the edge of a small waterfall so that water would flow through the trough at a depth of about two inches and arranged so that by raising or lowering the lower end the velocity of the water could be varied. The bottom of the trough was a rough unplaned board which supplied the nymphs with a foothold. Three almost mature *Chirotenetes* nymphs averaging 12 mm. in length were put in the trough about a third of the distance from the lower end where the velocity on the bottom was 1.4 feet per second. The velocity was gradually increased until all the nymphs let go their hold and the velocity of the water then measured. The greatest velocity which these nymphs could withstand was one where the velocity on the bottom of the trough was 4.3 feet per second. With three nymphs 9 to 10 mm. in length it was found that these could maintain their hold until a velocity of 4.8 feet per second was reached.

A series of experiments was then carried out in order to observe the actions of the nymphs of *Chirotenetes* more closely in currents of various velocities and to compare their actions with those of the larvae and nymphs of other insects inhabiting swift water. The procedure was as follows. The trough was arranged with a slight current and the forms to be experimented with were placed in the trough about a third of the distance from the lower end. The current was then increased, and the forms were observed and notes made as to their actions. The velocity of the water was then measured on the bottom in the middle of the trough and just off the bottom. The *Chirotenetes* nymphs used were of almost mature form and fresh specimens were taken frequently so that the results might not be vitiated by fatigue.

Exp. 1. Bottom velocity .4 to .8 feet per second.
Off bottom – 1.0 " 1.2 " " "
Chirotenetes nymphs able to swim and crawl rapidly.

Exp. 2. Bottom velocity .9 to 1.0 feet per second.
Off bottom 1.2 " 1.4 " " "
Chirotenetes nymphs able to crawl but barely able to hold their own against the current in swimming.

Exp. 3. Bottom velocity 1.4 to 1.8 feet per second.
Off bottom 2.2 " 2.4 " " "
Chirotenetes nymphs able to crawl but carried back at once by the current when loosened from foothold.

Exp. 4. Bottom velocity 1.0 to 1.9 feet per second.
Off bottom 2.1 " 2.8 " " "
Chirotenetes nymphs still able to crawl rapidly.

Exp. 5. Bottom velocity 2.2 to 2.4 feet per second.
Off bottom 2.9 " 3.0 " " "
Chirotenetes nymphs able to crawl slowly.

Exp. 6. Bottom velocity 2.8 to 3.6 feet per second.
Off bottom 4.3 " " "
Chirotenetes nymphs able to crawl slowly.
Epeorus and *Heptagenia* may-fly nymphs, a water-penny, a large stone-fly nymph and a black-fly larva were all able to maintain their

hold and move about. The large stone-fly walked up against the current with apparent ease.

Exp. 7. Bottom velocity 5.5 to 5.7 feet per second.

May-fly nymphs (*Epeorus*, *Heptagenia* and *Chirotenetes*), a small stone-fly nymph, a water-penny, a seine-making caddis worm, a black-fly larva and a fish-fly larva (*Chauliodes*) were put in the trough and the velocity gradually increased until the stated amount obtained. The stone-fly nymph walked up against the current with apparent ease; *Epeorus* clung securely but remained quiet; the black-fly larva maintained its hold but curled up and lay flat on bottom; the water-penny moved slowly backward; all the others lost their holds before this velocity was reached and did so in this order—*Chirotenetes*, *Heptagenia*, fish-fly larva, caddis worm.

The results of these experiments show that the nymphs of *Chirotenetes* clinging to the under surface of stones escape the main force of the current. The water in such places is moving very much less rapidly than nearer the surface, but it still brings constant and fresh supplies of food and oxygen to the nymph which may wander about in comparative security from many of the dangers which necessarily accompany life in swift water. When the nymph wanders out on the flat rock bed of the stream, it still is in a much reduced current, especially where the rock is covered with diatomaceous ooze or other algal growths. The results also show that the nymph is able to live in rather swift water but that it is scarcely so well equipped for a swift-water habitat as some of its associates with limpet-like forms of body. Nevertheless the nymph of *Chirotenetes* does possess a form of body adapted to life in flowing water. The hard smooth chitinous covering reduces the friction of the water particles to a minimum. The head is well rounded. The thorax gradually widens and is followed by a depressed abdomen which condition tends toward a limpet or Heptagenine form. The following experiments were devised to determine the mechanical or adaptive value of the *Chirotenetes* form for life in running water. A mass of grafting wax weighing 184 grams was moulded into the shape of a cone, the base of which was 5.7 cm. in diameter and the perpendicular 8.25 cm. A fine wire was put through the cone from the apex to the centre of the base. This wire was fastened to a small metal bar in the middle of the cone to prevent it from pulling out. The cone was attached to a 50-gram spring balance by means of a fine wire 33 cm. in length. When placed in a current of 1.65 feet per second the cone sank about 3 cm. below the surface of the water, and with the base upstream exerted a pull of 28 grams. The balance was held nearly horizontal and as close to the surface of the water as possible. There was considerable fluctuation in the amount of pull on the balance as a result of the unevenness of the current and probably to some extent to the imperfect form of the cone. However, it was found that the indicator of the balance remained at a certain point for a greater part of the time and also that this point was approximately the average of the highest and lowest points reached by the indicator. With the apex up stream the pull exerted by the cone, as nearly as could be observed, was 50 grams. The wax was then moulded into the form of a fish of the sunfish type and the pull exerted was 15 grams. A form of the trout type gave a pull of 6 grams with head up stream and 10 grams with tail up stream. A model of a *Chirotenetes* nymph gave a pull of 9 grams with head up stream and 16 grams with head down stream. In all these experiments the total amount of wax was used.

It was found that the kind of edge fashioned at the base of the cone was of great significance. For example in a current of 1.2 feet per second a cone with a sharp edge to the base exerted a pull of 40 grams, whereas with the edges well rounded the pull was decreased to 10 grams.

Another series of measurements in a current 1.5 feet per second gave the following results. A cone with a base 7 cm. in diameter with a sharp edge and a perpendicular of 11 cm.

gave a pull of 50 grams with the base against the current and a pull of 25 grams with the apex to the current. A cylinder 8.5 cm. in length and 5 cm. in diameter gave a pull of 18 grams. With one end pointed and directed toward the current, the pull was 6 grams, while with the blunt end to the current the pull was 17 grams. With both ends pointed forming a spindle the pull was 5 grams. A fish model and a *Chirotenetes* model each gave a pull of approximately 6 grams.

Comparison of the amounts of pull exerted by the various models is open to the objection that the area of greatest cross section was not kept constant throughout. Nevertheless the results demonstrate in a rough manner that the nymph of *Chirotenetes* possesses a remarkably efficient form of body. This explains in part how it is that *Chirotenetes* nymphs are found in association with the flattened limpet-like forms of the stream.

Food.—May-flies are herbivores. They feed almost exclusively upon algae, from the minute diatoms to the higher filamentous forms. The nymph of *Chirotenetes* has developed a very remarkable specialization by means of which it avails itself of the suspended edible plant material carried along by the current. The inner sides of the fore femora, tibiae and tarsi are fringed with long hairs interspersed with shorter fine ones. These are supplemented by copious short hairs on the labrum, and on the maxillary palpi and by longer ones on the labial palpi. When the nymph takes up a position in the current head up stream, the forelegs are held out in front of the head and flexed at the tibio-femoral joint so that the claws are almost contiguous on the surface of the rock. In this position the hairs of the forelegs and mouth parts meet and overlap in such a way as to form a straining apparatus. To demonstrate the use of this strainer a trough $51 \times 4 \times 3\frac{1}{8}$ inches was placed below an outlet from a tank and arranged so that a moderate current flowed through the trough at a depth of one and a half inches. A number of nymphs which had had no food for twenty-four hours were put into the trough at the lower end. They soon began to crawl forward along the bottom. A mixture of silt, diatoms and other forms of algae was sent down in the current and observations were made by means of a reading glass. The strainers were soon loaded with the material and four nymphs were observed to feed upon it. The elongated fringed labial palpi were extended to sweep in the materials caught, while the maxillary palpi working laterally and the glossae of the labium working vertically pushed the food materials back to the mandibles. The legs were moved at times to bring food within reach of the mouth parts. Any materials caught and not wanted were expelled by moving a leg outward and allowing the current to wash them away.

To determine what materials were available in the stream as food for the nymphs a plancton net was put out in the stream at various times throughout the year. The various forms identified are listed and the estimated abundance indicated by the numbers 1, 2 and 3, indicating few, abundant, and very abundant respectively.

A few quantitative determinations were made to ascertain the amount of food available for the nymphs. A small wooden trough four inches wide was placed in the creek in such a way that one end projected over the edge of a small waterfall. A current flowed through the trough to a depth of two inches and at an average rate of 4.0 feet per second. A plancton net of no. 12 mesh silk was hung at the lower end of the trough for sixty minutes. The catch was filtered through fine filter paper and then transferred to a measuring cylinder in 80 per cent. alcohol and allowed to stand for twenty-four hours, and the volume then read. The catch amounted to 14 cc., a considerable proportion of which consisted of silt. Of this catch it was estimated that at least 40 per cent. was silt and inedible matter and another 10 per cent. of fine material which would not be caught by the hairs of the nymphal apparatus, which would mean that 7.0 cc. of edible material was taken in sixty minutes by the plancton net. The data at hand accordingly indicate that at a velocity of 4.0 feet per second there is delivered on an area of 5,160 square mm. in sixty minutes 7.0 cc. of food material. Now

	July 9, '14	Aug. 2	Aug. 13	Aug. 28	Sept. 5	Sept. 11	Oct. 31	Dec. 30	Apr. 25, '15	June 25	July 6	July 13	Aug. 12
Navicula	3	3	3	3	I	I	3	3	3	I	2	3	I
Cymbella	3	I	2		2	I	I	2		I			I
Melosira	I	2		2	2	3	3	2	2		I		
Synedra	2			3		I	I	3	2	I		2	I
Cocconeis		2	I		I	I	I					I	I
Meridion		I							I				
Gomphonema			I				I	2	2	I		I	
Tabellaria					I		I	I					
Gyrosigma					I		I						
Cosmarium	3	I	I	2	I	I							
Scenodesmus	I	I	I		I	I	I					I	
Closterium	I	I	I										
Pediastrum	I	I	I	I	I	I							
Straurastrum	I												
Protococcaceae	I	I											
Cyanophyceae	I	I	3	3	3	I	2	2	I				I
Chantransia							3	2					
Tribonema		2	2	I									
Cladophora	2		3	3	2	2	3	2	2	3	3	3	I
Oedogonium												I	
Spirogyra	2				I		I					I	
Ulothrix	I	I							I			I	2
Microthamnion				3	3	3	3		2			I	3
Higher Plant Tissues	3			3	3	2	3			3	3	3	3
Euglena	I				I				I				
Diplophrys	I												
Ciliata					i		I		I				
Rotifera							I		I				
Crustacea							I			I		I	
Insecta		I					I		I			I	I

the plancton basket of a mature nymph is about 8 square mm. in area. If a nymph lives in a current of 1.5 feet per second, then in twelve hours there should be delivered on the plancton basket .05 cc. of food material. The capacity of that portion of the alimentary canal from the mouth to the end of the mid-intestine of a mature nymph was then calculated as .0065 cc. This would mean that this portion of the alimentary canal would be almost filled eight times in twelve hours with food material. The results of other catches with calculations as just described are given as follows:

Date	Available food per 8 sq. mm. in 12 hrs. at 1.5 ft. per sec.	Times capacity of alimentary tract	
1915			
June 25	.050	8	
" 29	.097	15	
July 6	.041	6	
" 13	.048	7.5	After heavy rains
Aug. 12	.066	10.2	After heavy rains

These results are estimates but conservative ones. They show that there is a considerable abundance of food material coming down in the stream even when conditions are adverse, that is, following flood time. Doubtless the nymphs avail themselves also of algal growths on the stones to which they cling, so that the plancton catch (including particles of higher plant tissue and some animal material) may be considerably augmented.

No calculations were made during the winter but during this season the creek is full of diatoms. All the stones and rocks are covered with a thick brown velvety covering of diatomaceous ooze, so that the food supply should be but little less than in the summer.

Examinations of the stomach contents of nymphs were made throughout a year. Determinations were rather difficult because of the fact that the materials were so very finely ground up. Diatoms were found at all times, but were particularly abundant from September to April and included all the forms listed in the plancton catches. Particles of filamentous algae were recognizable in most of the mounts but were difficult to identify. *Cladophora* and *Microthamnion* were identified and particles of a blue-green alga, probably *Oscillatoria*. Of the smaller green forms a few specimens of *Closterium* and *Scenodesmus* were found. Fragments of higher plant tissues were common. Of animal remains two rotifers were found in one individual, a small claw or mandible of some undetermined form in another, *Simulium* fan rays and remains of *Chironomid* larvae in several and pieces of chitin in a number. In all specimens examined there were considerable quantities of sand particles. Needham ('05) reports that for nine well-grown nymphs taken in Fall Creek (time of year not stated) "plant remains constituted in all cases fully half of the stomach contents." The plant food consisted largely of higher plant tissues but mixed with this were *Cyanophyceae*, *Chlorophyceae* and diatoms. Of animal food, four had eaten *Simulium* larvae and *Caenis* nymphs, seven had eaten nymphs of *Ecdyurus maculipennis* and one had eaten of a small platode and a young nymph of *Chirotenetes*. Morgan ('13) reports having found epidermis of roots, *Zygnema*, *Gomphonema*, may-flies and other insects in more than ten specimens. It appears that the nymph of *Chirotenetes* tends toward an omnivorous diet. No doubt a considerable number of small animals such as small *Simulium* and *Chironomid* larvae and protozoans lodge on the nymph's basket and are eaten as readily as the plant forms.

Relation to the Oxygen and Carbon Dioxide Content of the Water.—Chemical analyses during 1914-1915 showed that the water of Cascadilla Creek was quite normal as regards the dissolved substances during that period. There was no evidence that the amount of pollution was harmful to the organisms of the creek. The effect on the oxygen and carbon dioxide content of a small amount of pollution in a stream flowing several feet per second is probably very slight. Analyses from December 1, 1914, to August 10, 1915, show a comparatively high oxygen content throughout the year and a low carbon dioxide content—two factors of extreme importance to an aquatic organism. The samples for oxygen determination were taken from the creek in the gorge in bottles with a capacity of 250 cc. The bottle was allowed to stand uncorked for two minutes to allow entrained bubbles of air to escape and determinations were carried out at once. There is a possibility that a small quantity of entrained air still remained in the bottle but the results obtained do not represent the total amount of oxygen available, for the tumbling waters hold a large amount of entrained air which would be of extreme value to the nymphs. In winter at 0° C. the results show the water to be almost saturated with oxygen. In summer, although the amount per million cubic centimeters has dropped considerably, still the water is frequently supersaturated. (Fig. 5.) The Ohio State Board

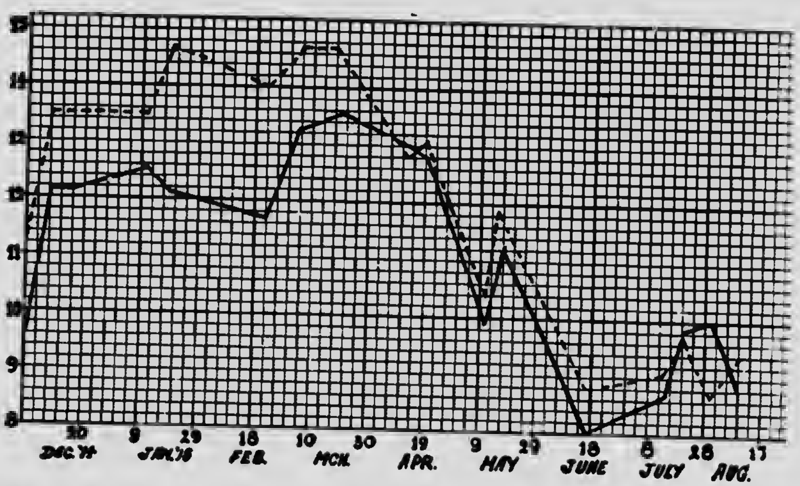


Fig. 5.—Oxygen content of Cascadilla Creek compared with amounts of saturation of water at same temperatures and pressure. ——— = oxygen content in parts per milllion. - - - - - - = amounts of saturation in parts per million.

of Health ('97) has reported water in Ohio supersaturated with oxygen during August, September and October. Shelford ('13) states that the carbon dioxide content is probably the best single index of the suitability of water for fishes because carbon dioxide in excess has a toxic effect. Chemical analyses of the water of Cascadilla Creek show a low carbon dioxide content throughout the year, especially in midsummer when during July and part of August the water was devoid of this gas.

The nymph of *Chirotenetes* obtains its oxygen supply by means of tufts of tracheal gills. There are seven pairs attached to the posterior lateral margins of the abdominal segments one to seven, one pair attached to the bases of the fore coxae and one pair at the bases of the maxillae. An estimate of the gill area presented by the nymph was made by counting the gill filaments in a cluster and measuring the length and diameter of a single filament. The results show a gill surface of about 230 square mm. presented by a mature nymph. The nymph is thus well equipped for obtaining a good oxygen supply in that it possesses fore coxal and maxillary gill tufts which are of unique occurrence among the known may-fly nymphs of our fauna. The extensive gill equipment probably bears some relation to the active habits of the nymph.

The following experiments were conducted to ascertain if the nymphs of *Chirotenetes* are dependent on current for their oxygen supply. On June 27, 1915, there was put into a large glass aquarium 2,000 cc. of water from Cascadilla Creek, containing 8.3 parts per million of dissolved oxygen and one part per million of free carbon dioxide at 18° C. Five nymphs were introduced into the water and on the bottom of the jar was placed a clean stone to which the nymphs might cling. On July 11 a rain added slightly to the amount of water in the aquarium. On July 13 a nymph died, and analysis of the water on July 14 showed 5.16 parts per million of oxygen and three parts per million of free carbon dioxide at a temperature of 21° C. The remaining nymphs died on July 20, having lived in the aquarium twenty-four days without food. Analysis on July 21 showed 9.9 parts per million of oxygen and no free carbon dioxide at a temperature of 15.1° C. Doubtless the nymphs had died of starvation.

For purposes of comparison 5,000 cc. of creek water had been put into a large glass aquarium on June 17, 1915, with no nymphs. Analyses of this water were made as follows:

		Temperature	Oxygen parts per million	Carbon Dioxide parts per million
1915				
June 17		20.2°C	8.01	1.5
" 18	24 hours	17.2	11.6	.5
" 24	7 days	11.0	9.68	.5
July 14	27 days	21.0	7.49	2.1
" 21	34 days	15.1	9.11	.0

On July 21 three *Chirotenetes*, three *Heptagenia* and three *Epeorus* nymphs (may-fly nymphs from flowing water of Cascadilla Creek) were put into this jar. The next morning the three *Epeorus* nymphs were found dead. Of the remaining nymphs four were alive on July 30, the other two having transformed to subimagos. On August 16 one *Chirotenetes* nymph was still alive in the jar, having been able to live for twenty-six days in water which had been standing sixty days. Analyses after the addition of the nymphs gave results as follows:

		Temperature	Oxygen parts per million	Carbon Dioxide parts per million
1915				
July 30	43 days	20.0°C	8.42	.0
Aug. 10	54 days	17.0	8.00	1.5

Just before Cascadilla Creek enters the gorge section, a pond, known as Dwyer's Pond, has been formed by a dam. Analyses of the water from Dwyer's Pond failed to show very marked differences in oxygen or carbon dioxide content from that of the tumbling water in the creek in the gorge. The samples were taken in the pond just below the surface and close to a clump of sedges in a situation where may-flies would be likely to occur. That *Chirotenetes* nymphs do not live in the pond cannot be because of lack of oxygen there or excess of carbon dioxide, nor because of lack of current, since the results of the aquarium experiments show that the nymphs are not dependent upon current for oxygen supply as are *Epeorus* nymphs apparently, for the latter die very soon after being placed in still water.

Associates.—In the classification of the ecological communities of the stream, the nymph of *Chirotenetes* belongs in the strata under the stones to the *Hydropsyche* or riffle formation (Shelford, '13). Its associates in Cascadilla Creek are as follows:

Ephemerida of the genera *Heptagenia, Iron, Epeorus, Ecdyurus, Ephemerella, Leptophlebia* and *Baetis.*

Plecoptera of the genera *Perla, Acroneuria, Neoperla* and *Pteronarcys.*

Neuroptera of the genera *Corydalis* and *Chauliodes.*

Trichoptera of the genera *Hydropsyche, Helicopsyche, Rhyacophyla, Leptocerus, Chimarrha* and *Polycentropus.*

Lepidoptera of the genus *Eliophila.*

Coleoptera of the genus *Psephenus* ("water-penny").

Diptera of the genera *Atherix, Chironomus, Diamesa, Tanytarsus, Tabanus, Eriocera* and *Tipula.*

Planarians.

Hirudinea.

Mollusca of the genus *Ancylus.*

On the smooth rock beds of the gorge, where the nymph of *Chirotenetes* occurs occasionally, are found larvae of *Simulium, Blepharocera* and *Hydropsyche* and Ephemerid nymphs of the genera *Heptagenia, Iron, Epeorus* and *Baetis.*

Among the stones of the creek have commonly been taken the blacknosed dace (*Rhynichthys atronasus*), the young of the common sucker (*Catostomus commersonii*), Johnny darter (*Bolesoma nigrum*), the nigger chub (*Exoglossum maxillingua*), the satin-fin minnow (*Notropis whipplii*), small common shiners (*Notropis cornutus*) and the dusky salamander (*Desmognathus fusca*).

Enemies.—Stomach examinations of some of the associates of *Chirotenetes* show that the two chief enemies are the large stone-fly nymphs, particularly *Perla media*, and the black-nosed dace *Rhynichthys atronasus.* Morgan ('11) reports having seen robins in Fall Creek gorge with the setae and abdomens of nymphs and subimagos projecting from the beaks. The period of moulting is an especially helpless time for the nymphs and at such time they are most liable to become the prey of enemies.

Severities of Stream Life.—Life in swift water is beset with many difficulties and dangers. Probably the most trying season for the nymphs of *Chirotenetes* is flood time. Stones and rocks are moved by the force of the current and during the spring flood the out-going ice scrapes and scours the creek bottom. The movement of stones, rocks and ice over the rock bed in the gorge of the stream at a time of high water can be distinctly heard. The nymphs are in danger of being crushed or swept out in the current over waterfalls or into unsuitable situations. A pool about one hundred and fifty feet south of Fall Creek is usually flooded in spring by a portion of the creek being diverted through it. After such a flooding *Chirotenetes* nymphs have been found in the pool. Another illustration as to how the nymphs are carried about during flood time was afforded in the course of the habitat experiments. A heavy rain one night caused the water in the creek to rise and the trough set out for an experiment was carried about ten yards down stream without being upset. The water was flowing over the trough to some extent and the stones, pieces of rock and gravel in the trough had all been shifted. The trough had contained thirteen almost mature *Chirotenetes* nymphs, but when it was examined only three of these remained, but twelve small *Chirotenetes* nymphs 7 to 8 mm. in length were found in the trough besides numerous *Baetis* nymphs and a number of *Hydropsyche* larvae.

After heavy rains the nymphs have to contend with large quantities of silt. Samples of water have been taken from the creek when it was loaded with sediment, the water filtered and measured and the residue weighed after drying in the air of the laboratory for several days. The results obtained are as follows:

Date	Amount of sample	Weight of sediment	Parts per million	Conditions
1914 June 28	2200 cc.	13.8 grs.	6200	Taken two hours after very heavy downpour of rain.
Aug. 20	2400	1.0	415	Taken morning after a heavy night's rain.
Sept. 2	1900	3.4	1800	Taken three hours after heavy rain.
1915 Jan. 7			400	Taken at time of a mid-winter thaw.
July 5	2200	1.3	590	Taken the day after heavy rains.

Professor Chamot has stated that turbidities in Six-Mile Creek frequently exceed 6,000 parts per million. Such enormous amounts of sediment result from the hilly nature of the watershed and the nature of the soil. The soil of Cascadilla valley consists of silty, clayey and stony loams. Heavy rains cover the hillsides with rivulets which bring down to the stream immense quantities of sediment. The water becomes yellow-brown in colour and so loaded with silt that the earthy odour can be detected a long distance from the creek particularly in the vicinity of waterfalls.

Flood time too carries out to the lake the plancton of the pools and ponds of the stream leaving the creek more or less deficient for some time of those suspended organisms upon which the nymphs depend to a large extent for food. This was shown by plancton catches taken before and after floods.

Needham ('16) points out the dangers from ice particles and "anchor ice" during the winter period.

Protection.—The nymphs of *Chirotenetes* receive protection from the stones, to the lower sides of which they cling. While the stones are in position, protection is afforded from the force of the current, from larger objects carried in the current, and where the space is small from larger enemies such as fish. The nymphs no doubt escape enemies by reason of protective colouring and agility. The chocolate-brown colour renders the nymph very inconspicuous on the dark coloured rocks of the stream bed, and the ability to dart quickly from place to place by means of strong strokes of the abdomen and fringed setae is of decided advantage. Nymphs in a current of water in a trough have been observed to loosen their hold allowing the current to carry them down a short distance and then to catch the bottom or side of the trough again. Doubtless such a procedure is used as a means of escape.

Regeneration.—The nymphs possess the power to regenerate certain parts. Frequently it has been observed that a nymph lacking a leg will after moulting possess a small leg. How many instars are passed through before the leg attains normal size has not been determined. The ability to regenerate a foreleg is of vital importance to the nymph.

The Subimago

Emergence.—There comes a time in the life of the nymph when some stimulus causes it to crawl up the side of a stone out of the water. The stimulus is probably supplied by a number of agencies of which the maturation of the sexual elements is doubtless the chief. The nymph crawls out just above the surface of the water. In a few seconds convulsive movements pass through the body, the head and thorax split along the mid-dorsal line and the body of the subimago slips out on to the stone. As soon as the wings are freed, they are spread, and at the same time the legs are extended so as to support the body of the insect. It soon takes a few steps or a little jump and the abdomen and setae are freed. After a few movements of the wings, legs and setae, the subimago flutters upward into the trees. Where no trees are near by they often flutter upward out of sight. The body of the subimago sometimes slips out on to the surface of the water and is carried down stream some distance standing on the surface film. A wave occasionally submerges the subimago or sweeps it away before it has freed itself from the old nymphal skin, thus ultimately bringing it to its death. Transformations occur in greatest numbers during the late afternoon and evening but some occur in the morning. The period of emergence is rather extended. The earliest observed emergence was on June 6 and the latest September 8, with the greatest numbers in June and July. Morgan ('11) reports emergings in great numbers in May, 1910.

Factors affecting the length of the Subimaginal period.—The subimaginal period is one of quiescence. The subimagos remain quietly on the leaves and twigs of the vegetation bordering the stream. They take no food, the mouth parts being degenerate. This condition prevails normally from twenty-four to thirty-six hours, at the end of which time the subimago moults, and the may-fly takes on the adult form. A set of experiments was carried out to determine the effects of temperature, light and humidity on the length of the subimaginal period. Three bell jars were set up. In one was placed a tray of calcium chloride, in another a tray of water and saturated blotters. The third was used as a control. Hygrometers hung in the jars showed that in the first the relative humidity was about 32 per cent, in the second practically at saturation, and in the third 66 per cent. Subimagos as they emerged were put into small wire cages. A male and a female were put into each cage and the cages put under the bell jars. Two series are given as typical:

Jar—low humidity (32%)

♀ emerged 12:25 P.M. Aug. 14, trans. 8:30 P.M. Aug. 15
= 32 hrs. 5 min.

♂ emerged 12:40 P.M. Aug. 14,—died.

Jar—normal humidity (66%)

♀ emerged 4:18 P.M. Aug. 14, trans. 9:00 P.M. Aug. 15
= 28 hrs. 40 min.

♂ emerged 4:10 P.M. Aug. 14, trans. 9:00 P.M. Aug. 15
= 28 hrs. 50 min.

Jar—saturation (100%)

♀ emerged 5:20 P.M. Aug. 14, trans. 1:00 A.M. Aug. 16 = 31 hrs. 40 min.

♂ emerged 4:50 P.M. Aug. 14, trans. 10:45 P.M. Aug. 15 = 29 hrs. 55 min.

♂ emerged 4:50 P.M. Aug. 14, trans. 11:15 P.M. Aug. 15 = 30 hrs. 25 min.

Jar—low humidity (35%)

♀ emerged 5:15 P.M. Sept. 10, trans. 6:40 P.M. Sept. 12 = 49 hrs. 25 min.

♂ emerged 5:15 P.M. Sept. 10, trans. 6:30 P.M. Sept. 12 = 49 hrs. 15 min.

Jar—normal humidity (50%)

♀ emerged 4:15 P.M. Sept. 10, trans. 4:10 P.M. Sept. 12 = 47 hrs. 55 min.

♀ emerged 3:55 P.M. Sept. 10, trans. 4:50 P.M. Sept. 12 = 48 hrs. 55 min.

Jar—saturation (95%)

♀ emerged 4:25 P.M. Sept. 10, trans. 4:45 P.M. Sept. 12 = 48 hrs. 20 min.

♂ emerged 5:05 P.M. Sept. 10, trans. 5:05 P.M. Sept. 12 = 48 hrs. 0 min.

Other series brought out the same results, namely that individual variations were greater than the variations among the jars.

Experiments were then conducted to determine the effect of darkness on the length of the subimaginal period. The exact time of emergence was obtained. The subimagos were transferred to wire cages some of which were put in a photographic dark-room and others on a window-sill in the laboratory in the bright light, at times partly in the sunlight.

Cage in light.

♂ emerged 4:10 P.M. Aug. 14, trans. 9:50 P.M. Aug. 15 = 29 hrs. 40 min.

♀ emerged 4:45 P.M. Aug. 14, trans. 1:15 A.M. Aug. 16 = 32 hrs. 30 min.

Cage in dark room.

♂ emerged 4:55 P.M. Aug. 14, trans. 12:20 P.M. Aug. 15 = 31 hrs. 25 min.

♀ emerged 5:20 P.M. Aug. 14, trans. 12:30 P.M. Aug. 15 = 31 hrs. 10 min.

Other experiments gave similar results, showing that darkness has no effect on the subimaginal period.

During the time these experiments were being conducted, the temperature varied considerably and a decided lengthening of the subimaginal period was noted when the temperature of the air lowered and a shortening of the period as the temperature rose. For example, on September 1 and 2, 1914, the temperature rose to 28.3° C. and the subimaginal period lasted 22 to 25 hours. On September 11, 1914, the temperature dropped to 15.5° C. and the period lasted 48 to 49 hours. A difference of 12.8° C. had doubled the length of the subimaginal life. A number of subimagos were placed in a cage which was then placed in the ice box of an ordinary refrigerator where the temperature was 8° C. The subimagos lived four days before transforming and some failed to transform. The length of the period thus varies greatly with the temperature but not with humidity or light.

Enemies.—The chief enemies of the subimagos are birds and spiders. Birds have been observed to fly out of the trees bordering the creek and catch the subimagos fluttering upward after emerging. All tree-inhabiting insect-eating birds doubtless feed upon the subimagos. Many subimagos are caught in spider webs. A fence along Fall Creek near Forest Home village usually has a great number of spider webs filling its spaces. One afternoon a large number of subimagos were emerging from the creek and a strong wind carried them toward the fence. Every web along the fence had one or more *Chirotenetes* subimagos caught in the meshes. Heavy rains and winds are destructive to the subimagos, beating them down and wetting the wings so that transformation cannot be successfully carried out.

Protection.—The only protection for the subimago consists in its dull colour and its quiescent habits. A subimago on the vegetation is usually difficult to detect.

THE IMAGO

Transformation.—At the subimaginal moult, the head and thorax of the subimago split along the mid-dorsal line, the wings are spread almost horizontally and with a few contractions of the body the adult form appears. When transformation occurs on a vertical surface, the body of the imago is bent down backward until the wings and legs are freed and then by movements of the wings the body is brought up until the legs are able to grasp the object above. The adult then walks away from the moulted skin.

Flight.—The males of *Chirotenetes* have a flight characteristic of the majority of may-flies. They appear over the stream usually after sunset, about twenty minutes before nightfall, in small swarms of thirty to fifty individuals. They are very graceful in flight, rising and falling in deep undulations of eight to fifteen feet, fluttering upward with the body held obliquely and then falling slowly on expanded wings and spread setae, with the body horizontal. The females do not take part in these flights but fly singly up and down the creek in long undulations. What factors induce the imagos to fly in the late evening have not been determined. It may be that this time of day is the safest, having been determined by natural selection, or it may be a negatively phototactic tendency carried over from the nymphal stage. When a female enters a swarm of males she is quickly caught by a male flying up beneath her. The male places his long forelegs over her prothorax and head and grasps her abdomen with his forceps. The arching of the body of the male in order to grasp the body of the female with the forceps brings the penes in position to be inserted into the openings of the oviducts at the apex of the seventh abdominal segment. Copulation lasts twenty-five to sixty seconds. The couples do not rise high but remain at almost constant level, frequently making quick turns and occasionally sudden drops. The male in separating lets go his hold with the forelegs first and finally with the forceps. Apparently the male returns to the swarm while the female flies up and down the stream in long undulations and soon begins ovipositing.

The mouth parts of the imago are degenerate and no food is taken during the short aerial life. The alimentary canal, however, is not degenerate but is filled with air and serves as a buoyant organ (Sternfeld, '07).

Oviposition.—Preceding oviposition the eggs make their appearance from the openings of the oviducts and form a spherical mass which is apparently held in position by the bending forward of the sternal prolongation of the ninth abdominal segment. The eggs are held together by very fine strands of a viscid substance. The female flies over the water with long deep undulations carrying the greenish egg mass and dips to the flowing water so that the egg mass is carried away in the current. The eggs scatter somewhat in the water and adhere to objects by means of the viscid strands.

The Egg.—The egg is almost spherical with a diameter of .2 mm. It is greenish in colour when mature, with the surface divided into very small polygonal areas and slightly roughened. The egg complement consists of 1,900 to 2,000 eggs. It was found that at a temperature of 22.5 to 25° C. they hatch in about fourteen days, while at a temperature of 13° C. in twenty-five days. In the eggs ready to hatch the eyes and ocelli of the embryos can be seen moving up and down. After a considerable period of movement of the head in this way, a crescentric slit appears on the egg shell at the point where the head has been moving, and then the head pushes out through the opening. Soon the tips of the antennae are freed and extended. The pairs of legs follow in succession accompanied by considerable movement of the body. At the end of ten minutes all the body is freed except the tip of the abdomen and the setae; and in two minutes more the nymph is able to shake off the egg shell. The nymphs at hatching are .8 to .9 mm. in length, without gills, with forelegs unfringed and having eyes and ocelli of equal size. They moult six days after hatching and still show no signs of gills but the forelegs possess a few hairs along the inner margins. It was found that the eggs of *Chirotenetes* could be artificially fertilized. The testes of three males were put into water in a Syracuse watch glass and teased out. The eggs of a female were then put in the vessel and stirred about gently for a few minutes. The contents of the watch glass were left standing for an hour, then the water was poured off with the bits of tissue resulting from the dissections. Fresh water was poured over the eggs, and the watch glass covered and kept on the laboratory table. The eggs began to hatch eleven days later and continued to do so for nine days.

Length of Life.—How long the adults live under normal conditions and whether males return to swarm a second or third evening has not been determined. Reared imagos kept out of doors in a large wire cage in which was put a leafy branch of a tree, lived four and one-half days.

SUMMARY

The results of the investigation are as follows:

1. The nymphs of *Chirotenetes* show a very decided habitat preference for the lower surfaces of stones and rubble as against smooth open sheets of rock, and a slight preference for rubble as against small stones.

2. The nymphs are negatively phototactic.

3. The nymphs live in a very much diminished current beneath the stones and rubble of the stream.

4. The nymphal form of body is well adapted for a more or less active life in running water.

5. By means of fringes of hairs and bristles on the forelegs the nymphs are able to strain out suspended organic materials of the stream for food purposes.

6. The suspended plant and animal forms in the current are sufficient in amount to supply the food requirements of the nymph.

7. The water of Cascadilla Creek throughout nine months was neither excessively polluted nor contained excessive amounts of dissolved substances, so as to be harmful to the nymph. The oxygen content was high and the free carbon dioxide content low.

8. The nymph is not dependent on current for oxygen supply.

9. Temperature has a very marked effect on the length of the subimaginal period, while humidity and light have no effect.

10. The eggs of *Chirotenetes* can be fertilized artificially.

It appears that food has been the factor determining the habitat of the nymph. With special equipments in bodily structure it has pushed out into the current and made use of the current to bring it food. Out in the swift water it has taken to the lower surfaces of the stones and rubble for shelter from the dangers accompanying life in swift water and for protection from enemies.

While the activities of the nymph are concerned primarily with the acquisition of food, the activities of the adult are concerned with reproduction. The degeneration of the mouth parts, the inflation of the alimentary tract, the well developed wings, the elongated forelegs and large compound eyes of the male are modifications tending to insure the perpetuation of the race.

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FIG.

EXPLANATION OF PLATES

PLATE I

FIG. 1. Nymph of *Chirotenetes albomanicatus* Needham.
2. Pitot-tube as used in Cascadilla Creek.

PLATE II

3. Upland portion, Cascadilla Creek.
4. Upland portion, Cascadilla Creek.

PLATE III

5. Gorge portion, Cascadilla Creek.
6. Gorge portion, Cascadilla Creek.

PLATE IV

7. Cascadilla Creek after descent into Cayuga Valley.
8. Flats portion, Cascadilla Creek.

PLATE V

9. Winter conditions, upland portion, Cascadilla Creek.
10. Flood conditions, upland portion, Cascadilla Creek.

PLATE I

Fig. 1.—Nymph of *Chirotenetes albomanicatus* Needham.

Fig. 2.—Pitot-tube as used in Cascadilla Creek.

PLATE II

Fig. 3.—Upland portion, Cascadilla Creek.

Fig. 4.—Upland portion, Cascadilla Creek

PLATE III

Fig. 5.—Gorge portion, Cascadilla Creek.

Fig. 6.—Gorge portion, Cascadilla Creek.

P TE IV

Fig. 7.—Cascadilla Creek after descent into Cayuga Valley.

Fig. 8.—Flats portion, Cascadilla Creek.

PLATE V

Fig. 9.—Winter conditions, upland portion, Cascadilla Creek.

Fig. 10.—Flood conditions, upland portion, Cascadilla Creek.